Plastics: Floating Ethical Flotsam

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Introduction

“I just want to say one word to you. Just one word,” confides family friend Mr. McGuire to newly minted graduate Benjamin Braddock. “Plastics. There’s a great future in plastics.”

“Think about it,” he intones to a bewildered Ben. “Will you think about it?” [1].

Plastics have come a long way since *The Graduate* and a confused Dustin Hoffman. From its initial days to current times, plastic has become indispensable, interwoven into the very fabric of our lives. It is inexpensive, lightweight, clean, durable, and versatile. Uses range from toys to weapons of war to packaging to medical devices. And where would we be without Scotch tape, especially during the holidays?

It also, apparently, lasts forever, as every piece of plastic ever invented is still with us [2]. While plastics live on in landfills across the planet, of most recent concern is the effect on the oceans, now host to sizable “garbage patches” in the Pacific, Indian, and Atlantic Oceans. Contrary to popular opinion, these are not giant islands of plastic bags and other recognizable debris; rather, the most vexing components are very tiny pieces of plastic resulting from the breakdown of larger items or directly infused as microbeads, prevalent in personal care products.

This paper examines one of the ocean gyres, the “Great Pacific Garbage Patch,” as a case suitable for classroom use in discussing engineering ethics. Specifically, it explores background, problem definition, ethical considerations, potential classroom usage, and overall significance.

Background

Synthetic plastic is a relatively recent invention, dating to the mid-nineteenth century. The word derives from the Greek “plastikos,” which means “able to be molded” [3]. After a number of false starts, including “Parkesine,” developed in 1862 by British inventor Alexander Parkes, and Xylonite, an 1869 product attributed to Daniel Spill [4], the first mass-produced plastic was celluloid, invented by American John Hyatt in 1869, who was initially trying to develop a substitute for ivory [2]. Phelan & Collander, a billiard ball manufacturing firm, was offering $10,000 for an alternative [5] because the popularity of billiards, with its ivory cue balls, and piano keyboards was resulting in the wholesale slaughter of elephants, affecting supply and threatening species extinction. While Hyatt never collected his reward, his polymer, which consisted of naturally occurring cellulose treated with camphor [5], was moldable into various shapes, thus reducing dependence on natural substances such as ivory and bone [2]. Celluloid was used for a host of consumer products, including hair combs, dental plates, ping pong balls, removable collars and cuffs, and the first synthetic fabric, Chardonnet silk [5], [6].

Commercial success was based on Hyatt’s development of a technology for molding celluloid, and the use of the substance persisted until 1949, eventually replaced by newer, less flammable plastics. His machine has been hailed as a “direct forerunner” of modern injection molding [5].

Hyatt's invention foreshadowed a manufacturing revolution, starting with the successful launch of Bakelite in 1907, developed by Belgian-born scientist Leo Baekeland, who graduated from the University of Ghent with a degree in chemistry and began work as an assistant professor. After a short career of teaching pure chemistry, however, he discovered that he was more interested in applications, and he and his new wife immigrated to the US in 1889, where he began work for what would become Eastman-Kodak. His subsequent invention of Velox, a new paper that allowed for photography using artificial light, and the sale of his rights to George Eastman made Baekeland a rich man, able to independently pursue further applications of chemistry [6].

At that time, scientists around the world were actively engaged in researching applications for phenol-formaldehyde resins as a source for shellac, then laboriously produced by scraping the secretions of female East Asian lac bugs from trees. Since each kilo of shellac required the demise of 50,000 to 300,000 insects, or more than 1 trillion to meet world demands [7], an alternative was highly desirable. Using an autoclave dubbed the "Bakelizer," Baekeland and his assistant, Nathaniel Thurlow, developed a new substance that was quickly moldable and, more importantly, capable of maintaining its shape after being heated or treated with solvents. A few years later, Baekeland and Thurlow founded the Bakelite Corporation, initially producing electrical insulators [6].

Bakelite proved to be an enormous commercial success to both manufacturers of electrical and automobile components and the general public. It was "The Material of a Thousand Uses," ranging from jewelry to washing machine pump rotators [6]. Even the celebrated *Titanic* sported Bakelite items: in addition to passengers' personal effects, lookout Frederick Fleet's telephone in the crow's nest used to report "Iceberg right ahead" and first-class corridor handrails were made of Bakelite [8].

As indispensable as Bakelite seemed, its eventual downfall was an inability to retain vibrant color. Based on resins, Bakelite's natural color was amber and, due to required fillers to reduce brittleness, other colors were "dull and muddy" [6] and tended to fade with continued exposure to light [9].

After the success of Bakelite, further refinement of plastics followed in rapid succession, accelerating in the 1950s: 1908, Celophane [sic]; 1910, PVC; 1931, Plexiglas; 1938, Teflon; 1939, Nylon; 1948, ABS; 1953, Lexan; 1954, Styrofoam; 1965, Kevlar [4]. Although some of these are unfamiliar to the casual user, they are central to our contemporary lifestyle: Lexan, for example, is a bulletproof resin-based thermoplastic used for items such as automobile windows and headlights, computer and telephone cases, DVDs, and reusable drinking bottles [10]. ABS is an impact-resistant extrudable plastic used to produce many common objects, such as LEGOs, small appliances, keyboard caps [11]. It is also a low-cost substance used for 3D printing [12].

Due to the efforts of Hyatt, Baekeland, and generations of successive scientists and inventors, plastics are now firmly entrenched in our lives. Every day, we wear clothing impregnated with plastics, apply plastic-infused makeup, brush our teeth and wash our hair with microbead-studded toothpastes and shampoos, drive cars with plastic components, use plastic-based computers and telephones, imbibe liquids from plastic bottles and styrofoam cups, cook with Teflon-coated pots and pans, protect leftovers in plastic wrap or containers, write with plastic pens and pencils, entertain ourselves with e-readers and tablets covered in plastic, play with plastic toys, watch plastic DVDs; in short, not a day passes without humans confronting plastics in multiple guises.

Problem Definition

As with any invention, the intersection of humanity and plastic introduces debatable consequences and ethical conundrums: Are our lives truly enhanced? Is this progress sustainable? Is the litter produced from throw-away plastics harming the environment? Is our current technology unwittingly limiting future generations from experiencing similar benefits? And, perhaps most importantly, are we simply overproducing common plastic items, such as bags and bottles?

The statistics are truly mind-boggling. Since the 1950s, humans have produced 18.2 trillion tons of plastics worldwide, with China, Europe, and the US generating the most [13]. Annually, in the US alone, we use 100 billion plastic bags, enough to circle the Equator 1,330 times [14]; we purchase 50 billion water bottles, about 13 per person per month, and dispose of 25 billion styrofoam coffee cups [15]; Americans use about 500 million plastic straws per day, about 1½ per person [16], and dispose of 192 tons of freezer package waste from burgeoning meal preparation companies, such as Blue Apron, let alone the millions of tons of plastic debris—air bags and styrofoam peanuts—used for protection of goods in the 165 billion packages mailed annually from online retail outlets [17]. Suffice it to conclude that we are wallowing in plastic products and the resultant waste.

Dealing with the copious waste generated by use of plastics introduces truly vexing questions. As Figure 1 from the EPA shows, just a tiny sliver (9.1% overall) is recycled, and most ends up in landfills [18] or in the planet's oceans, regardless of international agreements to avoid such practices.

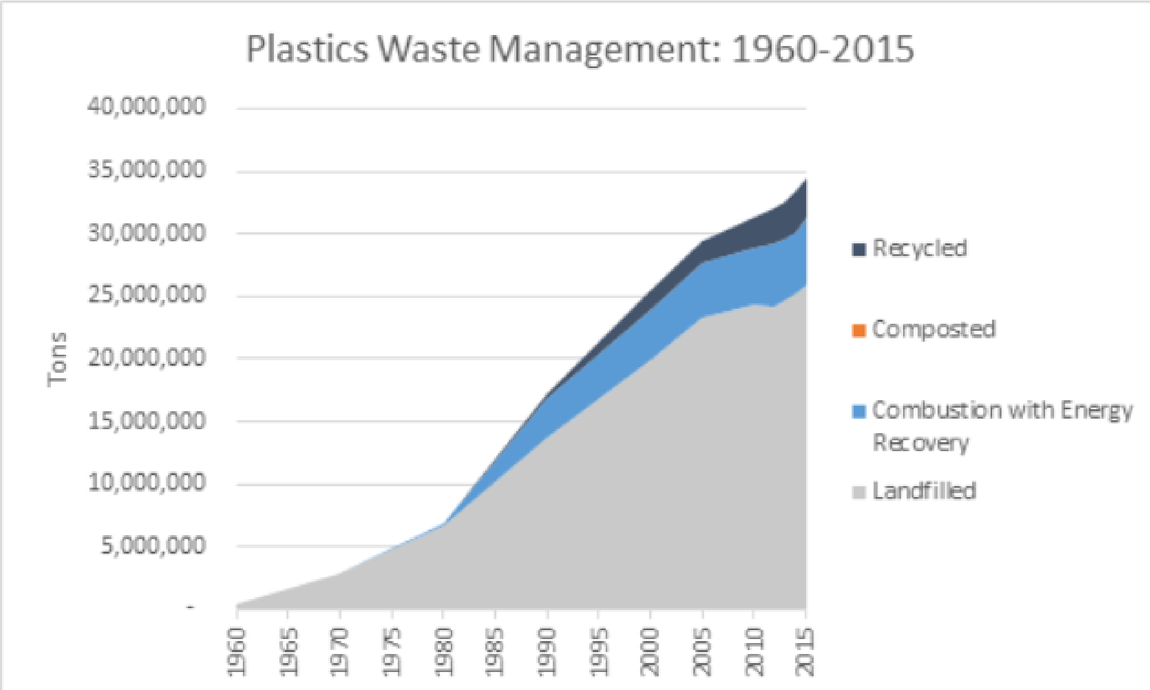

Figure 1. EPA plastic waste statistics [18]

International Legislation

Two international treaties address the issue of ocean dumping:

1972: London Convention (Prevention of Marine Pollution by Dumping of Wastes and Other Matter). The 22 articles constitute an agreement that participating nations will, "without delay," work to protect the marine environment from human-introduced pollutants. Annex I, in particular, prohibits the dumping of "Persistent plastics and other persistent synthetic materials, for example, netting and ropes, which may float or may remain in suspension in the sea in such a manner as to interfere materially with fishing, navigation or other legitimate uses of the sea" [19, p. 11]. Some 87 nations have signed onto the convention as contracting parties, including the world's most prolific plastics generators—China, Europe, and the US—as well as nations representing most continents.

1996: London Protocol. This document updates and rewrites the London Convention prohibitions. Some 50 countries, not including the US, have agreed to the Protocol's stricter stipulations [20].

Individual countries have passed similar protective legislation affecting specific areas; in Europe, for example, countries bordering the Baltic Sea agreed to the 1974 Helsinki Convention, which focused on technical issues related to pollution control, and the 1992 update, which takes into consideration "the seafloor and coastal zone . . . also its drainage area" [21].

Ocean dumping in the United States is governed by the 1972 Ocean Dumping Act (formally titled “Marine Protection, Research and Sanctuaries Act”) and its 1988 update. According to the EPA, the act “prohibits dumping into the ocean material that would unreasonably degrade or endanger human health or the marine environment” [22]. It is, however, primarily concerned with protecting US territorial waters, not the open ocean [23].

The London Convention, Protocol, and individual country legislation have attempted to identify major sources of marine pollution and offer remediation imperatives. However, the international treaties were hampered by two major limitations: an “inability to recruit sufficiently wide participation, especially among developing coastal states, and a clearly inadequate compliance system” [24]. Furthermore, since the bulk of ocean plastic comes from land [25], strictures against ocean dumping address only a small part of the problem.

The Gyres

As laudable as these attempts at curtailing ocean dumping are, the existence of five great garbage gyres in the Pacific, Indian, and Atlantic Oceans belie their effectiveness. These massive vortices are fed by a daily diet of trash, including significant amounts of plastics. As a 2016 report from the World Economic Forum states, plastics enter the ocean at an alarming rate: to date, some 150 million metric tons, and annually, “8 million tonnes of plastics leak into the ocean—which is equivalent to dumping the contents of one garbage truck into the ocean every minute. If no action is taken, this is expected to increase to two per minute by 2030 and four per minute by 2050.” Ultimately, concludes the report, by 2050 the weight of marine plastics will dwarf that of fish [26, p. 7]. Clearly, this document is a clarion call for action to thwart a potentially catastrophic effect on the world’s economy and a major food source.

Of the five gyres, the “Great Pacific Garbage Patch” (GPGP) is the largest, consisting of two areas, joined by a trail of trash: one off the coast of Japan and another between California and Hawaii (see Figure 2). The GPGP was discovered in 1997 by yachtsman Charles Moore and christened by oceanographer Curtis Ebbesmeyer [27]. As a NOAA document suggests, calling these areas “patches” is a misnomer, leading people to envision floating islands of discarded shopping bags and soda bottles. A patch covers a small area, such as a patch sewn over a hole in the elbow of a favorite jacket. The garbage gyres, however, are “spread across the surface of the water and from the surface all the way to the ocean floor” [28].

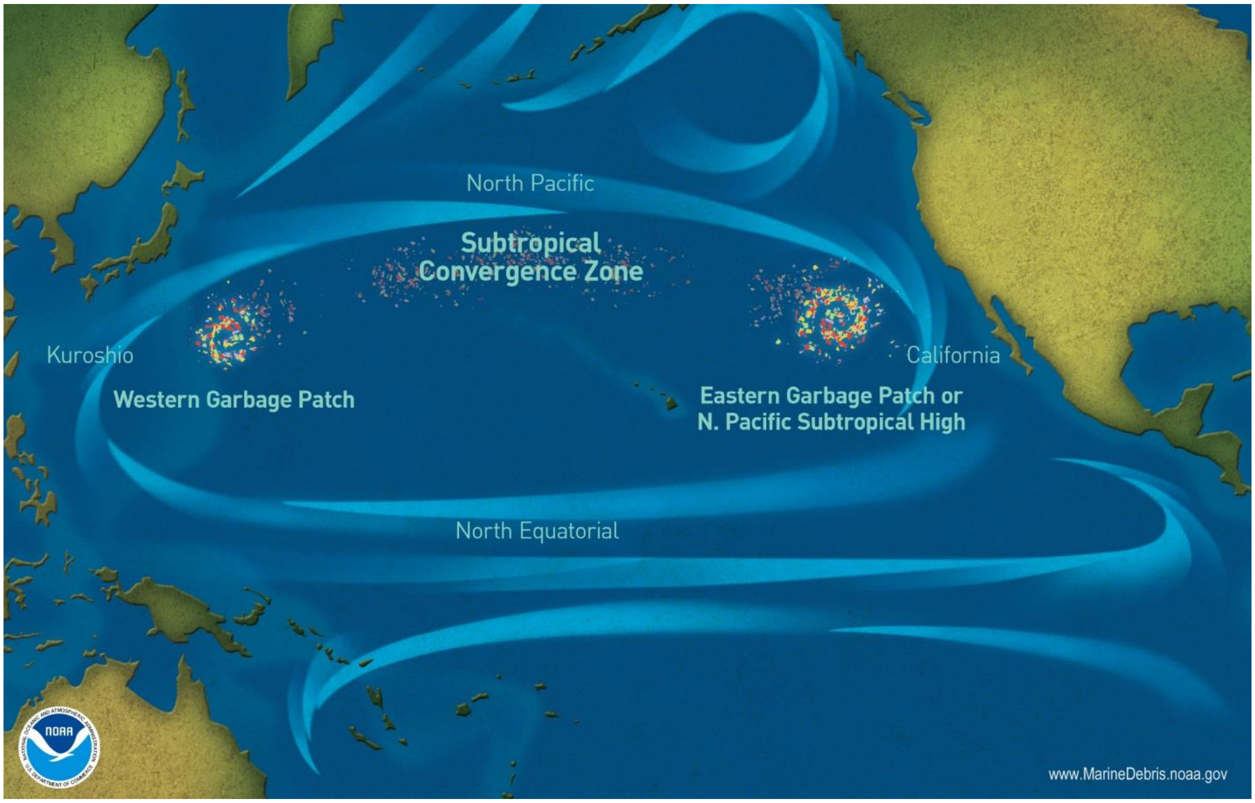

Figure 2. The Great Pacific Garbage Patch [28]

Collectively, these two areas cover an enormous expanse, estimated at twice the size of Texas, and weigh about 7 million tons [29]. A recent study indicates that about 8% of the total consists of microplastics, or about 1.1 to 3.6 trillion pieces of plastic, and that patch pollution is “increasing exponentially” compared to surrounding areas [30].

Considering the consequences of the gyre is extremely important, as plastic never biodegrades due to polypropylene bonding, which is impervious to organic decomposition processes; it will always be with us [31]. Some popular literature reports that, for example, it takes 450 years for a plastic bottle to biodegrade, straws take 200 years, and plastic bags a relatively quick 20 years [32]. These guesstimates, however, are wishful thinking; once created, plastic stays. Rather than biodegrading, it breaks down into smaller and smaller pieces, insinuating itself into innumerable environmental niches.

In the ocean gyres, plastics accumulate in varying sizes:

- Microplastics (0.05-0.5 cm)
- Mesoplastics (0.5-5 cm)
- Macroplastics (5-50 cm)
- Megaplastics (above 50 cm) [33]

About 92% of the GPGP mass consists of megaplastics, and “ghost nets,” abandoned fishing nets, account for nearly half of that. Ghost nets threaten larger marine fauna, which can become entangled and die; about 100,000 marine mammals and birds die or are injured annually from megaplastics [27]. These larger plastics break down into smaller bits as they bob in the patch. Some resemble birdseed or dust; others are microscopic [34]. The result is similar to confetti in a snow globe [35]. Smaller creatures may ingest meso and microplastics, mistaking them for plankton. They then enter the food chain, as seafood is eaten by hungry humans or larger marine creatures [33].

Microplastics in the Food Chain

Marine creatures are a major food source. According to the United Nations Fish and Agriculture Organization, more than 75% of fish caught or cultivated is for human consumption, and consumption rates in Asia are the highest in the world, followed by Europe [36]. In developing nations, fish accounts for about 50% of total protein intake, and for the world population, fish provides nearly 20% of protein for 1.5 billion people, 15% for another 3 billion [37]. In the US, nutrition studies indicate that approximately 80% of Americans include fish in their diets on a monthly basis [38], and current federal dietary guidelines emphasize increasing fish intake to 8 ounces weekly, particularly for pregnant or breastfeeding women (8-12 ounces). Especially recommended are those species low in mercury contamination: “salmon, anchovies, herring, shad, sardines, Pacific oysters, trout, and Atlantic and Pacific mackerel” [39, p. 24]. Worldwide, fishing and seafood consumption rates show a dramatic increase, notably in China, with an overall anticipated 19% increase by 2026 [40].

Seafood enthusiasts, however, are eating more than protein, as are marine creatures. Two studies, in particular, confirm that humans consuming fish/shellfish are also ingesting microplastics. In 2014, researchers at the University of Ghent examined the presence of plastics in two shellfish specifically grown for human consumption: blue mussels and Pacific oysters. They conclude, “the annual dietary exposure for European shellfish consumers can amount to 11,000 microplastics per year” [41, p. 65]. Richard Thompson, a University of Plymouth (UK) professor who has published dozens of scientific papers on microplastics in marine environments, concluded that about one-third of the 500 fish he examined from the English Channel had ingested microplastics [42], fish probably destined for British dinner plates.

Although scientific research on the effects of microplastics is in its infancy, several studies on both sea creatures and humans indicate a potential for harm. As Sam Levang, a researcher at the Woods Hole Oceanographics Institute, bluntly states, “recent lab studies do suggest that strange things can happen to an organism with a belly full of plastic” [35].

Effects on Marine Fauna

Numerous studies of shellfish (see, for example, [43]-[45]) indicate that microplastics can affect the digestive systems and immune system regulation of mussels and oysters. Studies of larger creatures, specifically European sea bass, widely consumed in Europe, and salmon reveal that fish are also susceptible to the effects of microplastics. Sea bass livers are affected by the PVC additive, constituting “an early warning signal on the chemical and physical hepatic stress on this species” [46]. Zwollo et al., studying the effects of phthalates (a plasticizer added for enhanced flexibility and durability) on juvenile wild salmon, conclude that the substance affects the fishes’ ability to produce antibodies, which "will make fish more susceptible to infection, and predictably increases their risk for disease and mortality in polluted waters" [47].

Other products from the sea may also be contaminated by microplastics. Researchers at two Shanghai universities examined table salts from retail outlets and discovered that sea salts contained 550-681 particles per kilo, predominantly cellophane [48]. While these concentrations are quite low, especially compared to the Belgian bivalve study, taking into consideration the amount of salt an average person consumes daily, the cumulative effect may be appreciable.

Effects of Humans

How microplastics affect human beings is currently unknown. However, given the ubiquity of microplastics, many scientists have called for exploratory studies to identify effects. While this paper has limited considerations of microplastics to ocean debris, it is important to note that they permeate the environment, occurring in tap and bottled water, beer, clothing, personal care products, home furnishings, dust, and air [49]. A recent Medical University of Vienna small preliminary study even revealed the presence of nine different microplastics in human stool [50]. But no viable experiments have been performed with human subjects due to logistical and ethical considerations, and plastics have generally been considered "inert" and therefore relatively safe for humans [51].

There is, however, considerable speculation about additives, which, being chemically unbound, can leach out into the environment [51]. Smith et al. express concern about chemical exposure due to additives, and microplastics tend to absorb, like sponges, certain chemicals unfriendly to humans, such as PCBs. Potentially, microplastic contamination might affect "cardiopulmonary responses . . . inflammatory responses . . . nutrient absorption, gut microflora, and reproduction" [52]. Several nations, including the US, Canada, and EU countries, have banned the use of BPA (an additive to improve strength) and DEHP (an additive to increase flexibility) in infant bottles and toddler sip-cups, due to potential detrimental effects [53].

The lack of scientific data regarding the effects of plastics on human health is not a reason to ignore the issue. Rather, it should serve as an incentive for future research and, as Arizona State University's Rolf Halden suggests, "the development of smarter and safer materials for future use" [54].

Ethical Considerations

John Hyatt and Leo Baekeland undoubtedly could not foresee the revolution their products would augur, moving from a world of wood and stone to one overwhelmingly dependent on synthetic plastics. For more than a century, massive consumption of plastics has occurred without regard to disposal until relatively recently. Perhaps the EU commissioner for environment, maritime affairs, and fisheries, Karmenu Vella, sums it up best: "we have a situation where one year you are bringing home a fish in a plastic bag, and the next year you are bringing home that bag in a fish" [55].

Trash, especially non-biodegradable waste, is a moral problem, not simply an issue of adequate disposal. Gay Hawkins, author of *The Ethics of Waste,* sees the plastic bag as “the penultimate sign of environmental catastrophe” [56, p. 21] and suggests that dealing with waste is a habit, one concerned with organizing existence. Currently, part of western ethos is disposability, separating the self from waste and designating certain areas as “waste only” [56]; out of sight, out of mind as we throw things “away.” However, there is no “away,” and we apparently now see planetary oceans as vast waste dumps based on the concept that the oceans are self-cleaning, due to the actions of tides, currents, winds, and bacteria [57]. These act as filters, analogous to the human body’s liver, kidneys, and lungs [58]. When the input rate exceeds the cleanup rate of natural processes, however, trash accumulates at an alarming rate. The current practice of adding millions of tons annually simply overwhelms nature.

The problem is of urgent global concern; as United Nations Environment Executive Director Under-Secretary-General Erik Solheim warned at a recent UN environmental assembly in Nairobi: “We’re facing an ocean Armageddon…. At the current rate, we’ll end up with more plastic in the oceans than fish by the middle of the century, and ultimately that comes back to our own food chain. We need to understand that if we kill our oceans, we also kill ourselves” [59]. That same assembly passed a resolution in 2017 vowing to combat marine plastics pollution, and a resultant *ad hoc* committee has identified four barriers to overcome: legal, financial, technological, and informational [60].

The issue of ocean pollution falls under the general purview of environmental ethics, particularly a consideration of direct human influence on the natural world. A relatively new field, environmental ethics has adopted a more or less anthropocentric view of the ecosystem: how changes in the natural world specifically affect our species [61]. More recent theorists, however, are exploring the concept of “deep ecology,” that is, “nature as a whole has moral value” [62, p. 97], irrespective of interplay with the human population. Viewing the natural world as having an intrinsic worth is, indeed, one of the major challenges facing environmental philosophers [63].

Ocean gyres, particularly the GPGP, are a topic ripe for ethical reflection in engineering classes for a number of reasons. First, it involves public safety, which engineers in all fields pledge to uphold as professionals in their respective areas. Second, it involves establishing and maintaining a sustainable environment, which engineering codes of ethics also address. And third, potential solutions for cleanup will be developed by engineering professionals, acting in concert with scientists and industry.

Moral Responsibility

Identification of ethical concerns is an important first step to solutions. Perhaps the most important ethical issue associated with marine plastics is moral responsibility, which refers to “arrangements appropriate for addressing widespread harm and wrongdoing associated with the actions of groups” [64]; in this case, a collective responsibility on the part of the world’s inhabitants. Recycling is an example of collective responsibility, and even though it is just the tip of a strategic iceberg, some countries have made impressive inroads. Denmark, for example, has banned single-use plastic bags; the average Dane uses just four per year, as compared with the average American, who uses one per day [65] or hundreds annually. Some 28 European nations are currently formalizing an agreement to ban specific single-use plastics, including straws, cutlery, plates, and cotton swabs. In the near future, the ban will extend to stirring sticks, balloon sticks, and polystyrene take-out containers [55].

One of the quandaries associated with responsibility involves ascribing ownership of the problem. Although third world and developing countries are the worst offenders, due to rapid economic change and inefficient waste management infrastructure [66], it is international in scope, with worldwide drift patterns that carry microplastics into uninhabitable zones, such as the Arctic [67]. Zoë Robaey, in her 2015 article on responsibility, ownership, and genetically modified seeds, effectively argues that all are responsible, as all have a duty to prevent harm [68]. The same argument can be applied to marine plastic pollution: all own the problem, since plastics permeate all cultures on the planet.

Accountability

A second concern related to moral responsibility is accountability, which involves justifying actions and judgments **[**69**],** especially in regards to business ethics. The root of the problem, in addition to the crux of viable solutions, lies with the businesses producing plastics and using them for packaging, which constitutes about 40% of all plastic production and subsequent pollution [70]. "This is their crisis to tackle," argues Annie Leonard, Greenpeace USA's executive director [71]. While individual and national recycling efforts are productive, companies produce plastics at a far greater rate than recycling efforts can combat. Leonard continues, "We need corporations . . . to step up and show real accountability for the mess they've created" [71].

Some companies are taking initial steps. Coca-Cola, for example, has pledged to start collecting and recycling its plastic bottles, estimated at 110 billion annually. Unilever, Procter & Gamble, and McDonald's have all announced intentions to start producing and using more recyclable plastics, and the latter wants to recycle all restaurant plastic debris [72]. If these good intentions translate to action, that will have an appreciable effect on future contributions to the ocean gyres. It does not, however, address the current problem.

Protecting the Environment

While the plastic pollution problem may pale in comparison to other threats to the planet's oceans—climate change being foremost—it has an emotional effect on average people that global warming lacks. Few can view the widely circulated photo of a dead albatross chick's stomach filled with brightly colored plastic gizmos [73] or watch the viral video of Costa Rican researchers removing a straw from a sea turtle's nostril [74] without feeling a sense of revulsion and, perhaps, anger. That video, with a current viewer count exceeding 33 million, was, in fact, instrumental in initiating the plastic straw ban in Seattle and multiple other cities [75].

While municipal activities are laudable, they tend to focus on visible litter, not microplastics. Many coastal communities sponsor beach clean-up days as annual events. In Oregon, for example, the SOLVE program extends to 45 different sites along the Oregon coast, all of which are public, federal, or state-held land; in the past decade, volunteers have collected some 4,000 tons [76]. In California, 60,000 volunteers working at 1,000 sites collected 367 tons of debris and recyclables in 2018 [77]. While such efforts help to prevent plastics from entering the oceans, they do not address the problems extant in the gyres.

Engineers, however, are in a unique position to contribute significantly to technical solutions. Indeed, they are bound by their codes of ethics to be "good stewards of the environment," according to the code of the Society of Naval Architects and Marine Engineers [78]. Other engineering codes include sustainability as a major principle [see, for example, [79]).

The first step towards viable solutions is to identify the extent of pollution. Satellite-based mapping is currently occurring, from a Dutch entity, Ocean Cleanup, and the European Space Station [80]. Mapping can reveal the exact location and degree of pollution.

Several engineering inventions show promise for both upstream and downstream trash removal:

Mr. Trash Wheel: A product of Baltimore's Clearwater Mills, this device works like an old-fashioned waterwheel with a conveyor belt that sweeps trash off the surface. Designed for usage in rivers, where it helps to prevent trash from entering the ocean, since 2014 it has removed about 1.6 million pounds of debris [81]. However, it is limited to small areas; the GPGP would overwhelm its capabilities.

The Seabin Project: Like Mr. Trash Wheel, this device also has limited utility. It looks like a giant trashbin with a filter on top. Once submerged, an underwater pump suctions water through the top, and trash is pulled inside and drops into a catch bag, which is fine enough to filter out microplastics and oil. However, it too is very limited, collecting only about 1,000 pounds per year [82]. It is also requires relatively high maintenance: emptying the catch bag once or twice per day and cleaning the unit at least once monthly [82]. While it is ideal for marinas and other confined spaces, use in the GPGP is not viable.

SeaVax: The SeaVax is representative of several robotic vacuum devices, capable of treating 89.9 million liters of seawater a year. It is amphibious and can clean water of chemical pollution, such as sewage and oil, in addition to microplastics. However, the mechanism is still in its infancy and further development is reliant on donations and volunteer time [83].

Ocean Cleanup: Of the current technological systems dealing with ocean pollution, the Ocean Cleanup device seems to be the most promising. The brainchild of Dutch inventor Boyan Slat, it consists of "a 600-meter-long floater that sits at the surface of the water and a tapered 3-meter-deep skirt attached below. The floater provides buoyancy to the system and prevents plastic from flowing over it, while the skirt stops debris from escaping underneath" [84]. The system comes with a large price tag, about $1.35 million for the first working prototype, and collection estimates are 156 tons per year. Maintenance will be required about once every 45 days, to empty debris and bring it to shore for disposition. Slat, however, has raised over $30 million to finance the project and maintains a high social media profile [84].

Ocean Cleanup launched its maiden effort from San Francisco on September 8, 2018. It arrived at the GPGP in mid-October, was installed, and began cleanup operations. However, due to technical issues, the system is now in Hilo for "tweaking" [84]. If it works as planned, the system will remove 50% of the GPGP within five years. Interested observers can follow the project on Facebook, Twitter, or on the project's website: https://www.theoceancleanup.com/system001/.

One of the more fanciful solutions received an honorable mention in the annual Evolo Skyscraper Competition. In 2011, Serbian designers Milorad Vidojević, Jelena Pucarević, and Milica Pihler envisioned a series of underwater skyscrapers, "floating islands that will be used to remove and recycle the garbage patch. These are self-sustained structures organized by function hierarchy with four communication cores that connect three main programs—collectors at the bottom, recycling plant in the middle levels, and housing and recreational levels atop" [85]. Although it is currently at the conceptual stage, it is an intriguing, rather elegant solution that minimally intrudes on the marine environment.

Other engineering-related solutions include improvements to wastewater management systems with filters able to deal with microbeads and fibers from synthetic fabrics [86], development of recyclable/compostable packaging [87], recycling plastics into fuel or use in 3D printing [88]. Working with scientists, engineers can contribute to chemistry-based solutions, such as propagation of the newly discovered enzyme that consumes the PET plastic used for drink bottles [89], high-level recycling focused on plastics such as polystyrene (used for take-out containers), and designing new polymers more amenable to recycling [90].

Safeguarding the Public Health

As noted previously, the effect of plastics on humans is currently unclear, and many researchers are calling for increased studies. Notes one Woods Hole scientist, "Just because we don't see it doesn't mean it's not there" [91]. While a number of "fight plastic pollution" advocacy websites boldly proclaim that plastic is toxic to humans (see, for example, [92]), the truth is that empirical data does not support that conclusion—yet. In the future, concerted research efforts may establish connections.

It is also true, though, that improvements to the marine environment will result in better diets (and lives) for sea creatures and thus may affect human health. So in fulfilling the dictum to protect the environment, engineers will also safeguard human health.

Classroom Applications

The GPGP provides a timely vehicle for student exploration through an engineering ethics prism. Asking students to keep a log of their own plastic usage is illuminating as a starting point; plastic is so ubiquitous that we often overlook how frequently we encounter it. Today, for example, this author touched plastic even when opening mail: those envelopes with clear windows contain cellophane. She also ate a bagel for breakfast, sliced with a plastic-handled knife, with butter from a plastic-lined wrapper. Later, during a brief shopping expedition, she realized that in the flotilla of grocery carts exiting the market, only one shopper had provided her own bags; the other baskets were filled with single-use plastic bags to be transported home, unloaded, and discarded. These are daily occurrences and represent dozens of interactions. Once students have identified their own plastic contacts, they can devise a remediation plan to lessen usage. As Craig

Leeson, documentary filmmaker who produced *A Plastic Ocean*, suggests, “From knowing comes caring, and from caring comes change” [93].

A quick Google search indicates that numerous colleges are addressing the issue of plastic pollution, including Ohio State [94]; Carleton College [95]; University of California at Santa Barbara, San Diego, and San Francisco; University of Southern California [96]; and University of Georgia [97], to name just a few. Other websites include classroom activities, exercises, and project examples to inspire creative instructors.

Students can research any of the topics listed below as group activities and share their observations with the class via oral presentations, supported by written reports:

- Description of environmental impacts
- Ethical analysis of environmental impacts
- Identification and evaluation of current cleanup technologies
- Investigation of substitutes for plastics (using [25] as a basis)
- Home institutions’ disposal policies and recycling efforts
- Evaluation of home countries’ disposal and recycling efforts
- Exploration of “social plastic” (using [98] as a basis)
- Development of educational materials for home institutions
- Reuse of plastic items (projects such as Panama’s “Plastic Bottle Village” [99] and Oregon’s “Washed Ashore” [100])
- Application of appropriate ethical theories/principles (for example, deontology and utilitarianism)
- Connection to engineering ethics code provisions regarding sustainable development

Having students conduct their own research will hopefully reinforce both the complexity of the plastic pollution issue and the necessity of imaginative solutions to the three prongs of the problem—production and usage, disposal, and cleanup—all of which are intertwined.

Conclusions

Phenomena such as the ocean gyres are unfortunate side effects of a product so versatile that imagining life without it is difficult. For a century, plastic has been an almost indispensable part of human society, affecting every facet of life. Now we find ourselves in a moral quandary, and how we respond may determine quality of life for future generations.

As professional engineers, our students may be involved in the solutions to plastic pollution. So it behooves us, as teachers, to address the issue and foster an awareness of responsibility while they are still in a formative stage. Every student who sips from a plastic water bottle during class has a decision to make regarding the fate of that bottle: reuse, recycle, or toss it in the trash, where it will eventually join billions of other castaways bobbing in the world’s oceans, carried by currents to one of the great gyres.

At the very least, we can advocate for greater understanding of the complexity of this particular problem and the necessity of multi-pronged solutions: individual, municipal, national, and international. As Borrelle et al. note, “International collaboration is necessary to reduce the demand for single-use plastic products, shift to a sustainable plastics economy, and improve waste management infrastructure that promotes zero-waste” [101].

More than half a century ago, Rachel Carson wrote in *Silent Spring*, “If we are going to live so intimately with these chemicals—eating and drinking them, taking them into the very marrow of our bones—we had better know something about their nature and their power” [102, p. 25]. Although Carson was writing about pesticides, the same is true of plastics. Infused with chemical additives, they pose both challenges and opportunities: challenges to the health and habitat of numerous species and opportunities for imaginative and innovative solutions to a problem of our own making.

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